

SECTION IV

ENERGY BENEFITS OF PROTECTIVE GLAZING

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Energy Analysis of Protective Glazing Report

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ENERGY BENEFITS OF PROTECTIVE GLAZING

The concept that double glazing over stained glass would improve comfort and reduce energy needs dates back to at least 1861. The Dean and Chapter at York Minster Cathedral in England *"determined to glaze the outside of 'the five sisters' window, in the North Transept, with plate glass, to obviate the great draught of cold air through (sic) that expanse of glass."* The American glazing industry has promoted the use of protective glazing to save energy since the 1920s. The practice grew rapidly after World War II and again after the oil price shocks in the 1970s. Other technical, cultural and economic events added to the interest in double glazing. For further description, see Sections II & III of this study.

Today, energy savings remains among the three most popular ways to promote protective glazing, in addition to vandalism and weather protection. Sealmaster Magnetic Interior Insulating Windows claims savings of 25% or more of heating costs and up to 16% of cooling costs. General Electric claims improvements of energy efficiency up to 68% for one of their polycarbonate products. Such estimates may assume 24-hour occupancy and unnecessarily high interior temperatures, neither of which is common to houses of worship. Unfortunately, promotional literature from stained glass studios adopts these claims verbatim from the manufacturers. While promotional literature for PG often lists the energy benefits, the savings has been anecdotal or derived from technical formulae. The following report by Enermodal, Engineering, Inc., developed for this study, is the first to measure the savings with a computer model and weather data.

ENERGY AND INTERMITTENTLY-USED BUILDINGS

Worship spaces enclosed with stained glass are usually heated intermittently. To heat the worship space continually is very expensive. Typically, the ceilings are high, the walls are thick, the attics are uninsulated, the doors are drafty, and the stained glass windows-- originally conceived to be a single layer -- are made with many pieces of glass. When new, the stained glass windows were cemented on the inside and outside face which made them nearly as tight as a sheet of glass. However, over time the sealants and putties break down, the windows begin to buckle and bow, and gaps emerge throughout the window.

Since 1990, Inspired Partnerships has surveyed 160 houses of worship in Chicago. In 97% of the buildings, the worship space is zoned separately from the rest of the building. Heating systems installed prior to World War II are zoned with manual valves. More recent systems have electric valves controlled by thermostats. Church boilers are usually big, designed to heat large spaces quickly. Their heating capacity is typically over 100 BTUs per square foot regardless of where the building is located in the U.S. They are sized to quickly raise the temperature in the worship space to comfortable conditions, not for maintaining continuous interior temperatures.

There are large radiators under the windows to counter heat loss. The systems are usually steam heat, leaving practically no water to freeze on outside walls when temperatures are cold. Often, the systems were originally designed to be hand-fired by coal, with no plans to heat the buildings continually. In short, the systems were designed to heat quickly and then go off, letting the temperature of interior spaces drift very low without harm to organs, paint, plaster or wood. Other zones in the building might have been heated more hours each week.

Adding a layer of PG reduces heat loss from a window. To reduce conduction of heat, each layer of glass provides two air films, each with a resistance to heat flow. To reduce infiltration, PG is usually installed tightly. While the intent of PG is to reduce the rate of heat loss, there is little benefit in holding heat in an empty space. A comparison of the cost of living index to the cost of energy index back to the early 1900s shows that the cost of energy and the cost of living rose in somewhat parallel fashion. In other words, the prices of \$5 per ton of coal and a nickel for a loaf of bread in the early 20th century are relatively the same as \$100 per ton and \$1 per loaf today. Architects and builders traditionally understood the intermittent use of churches and realized that additional construction costs to improve the thermal shell of the building would have very long paybacks. Therefore, they redirected funds into big boilers (for short term heating), lighting, acoustics, and works of art...including stained glass.

QUANTIFICATION OF ENERGY SAVINGS

In order to understand the energy benefits from protective glazing, the National Preservation Center contracted Enermodal Engineering Inc. to create a computer model of a typical church. Enermodal has had considerable experience with measuring and rating glazing systems. They used the most advanced software available, DOE 2.1E, to analyze the energy used by St. John United Church of Christ in Evanston, Illinois. With 7,600 square feet of floor area, St. John is smaller than many urban churches, but is typical of many suburban and rural churches across the country. St. John Church has a fairly typical schedule of use. The sanctuary is used about ten hours per week. The offices are open about thirty hours per week, and the other major spaces are used about twenty hours per week.

Enermodal entered data on the walls, roofs, windows, air leakage, doors, and the outside weather in order to simulate the energy use at St. John. The estimates were then fine-tuned to match the actual energy use utilizing weather data from Chicago. Once a reasonably accurate match was made, the components of the building, thermostat settings, or the weather data could be changed to analyze the effects on the energy bills.

In 1982, the congregation spent \$7,544 (about \$19 per square foot) to install protective glazing over five large stained glass windows. According to the computer model, the resulting savings was only \$183 per year if the interior temperature was "lowered" to 68°F during unoccupied periods. Inspired Partnerships advises such temperatures to be as low as 45°F. With lower temperatures during unoccupied periods, the savings would be even less. And the savings would be lower yet if the PG was installed over plated stained glass windows consisting of several layers of glass.

If the church were "moved" to Toronto, the payback would be shortened to about 36 years. In Phoenix, the payback period would be extended to over 1,500 years! In short, the "minimum" payback period for any continental U.S. church would be decades, and represents a lower return on investment than an equal investment in a savings account. Even the energy savings claimed for protective glazing over residential or continuously occupied buildings is questionable, since this study endorses ventilating the air space to avoid window deterioration {see Section V}. Additionally, the PG at St. John has become cloudy, requiring additional artificial light to maintain interior light levels. Moreover, the glazing has become an eyesore when viewed from the outside.

Enermodal concludes *"The results show that the energy savings from protective glazing for an intermittently occupied church do not warrant the expense of installation."* *Therefore, the manufacturers or installers of PG have greatly exaggerated its value in energy savings when applied over stained glass in churches and synagogues. There are far better investments which congregations can make to lower their energy bills, such as programmable thermostats and zone valves. For further information, see their analysis following this introduction in Section IV -- Energy Analysis of Protective Glazing.

ENERGY ANALYSIS OF PROTECTIVE GLAZING

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ENERGY ANALYSIS OF PROTECTIVE GLAZING

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INTRODUCTION

Churches around the country have installed protective glazing over single-glazed stained glass windows to protect the glazing and to reduce the energy loss through the windows. Single glazing is not a good insulator; however, the actual energy and cost savings from a double-glazed system depends on building occupancy patterns and climate.

This study quantifies the potential energy savings from unvented and vented protective glazing installations in a church located in Evanston, Illinois. The energy savings are also calculated for this church in Toronto, Ontario; Seattle, Washington; Phoenix, Arizona; and Savannah, Georgia.

For this intermittently occupied church, the annual cost savings are as great as \$200 for Toronto. The cost of the protective glazing was \$8000 over 10 years ago, and this translates into over a 40 year simple payback. The results show that it is much more cost effective to use temperature setback and properly insulate the ceiling where it is accessible.

METHODOLOGY

The DOE-2.1E building simulation program (LBL 1995) was used to predict the energy use in the church. The church, St. John UCC, is a 7,584 square foot, brick church (Figure 1) and is located in Evanston, Illinois.

The energy performance of the church is also simulated in Toronto, Ontario; Seattle, Washington; Phoenix, Arizona; and Savannah, Georgia. For Evanston, Chicago weather data is used.

The church was built in two phases: the rear section dates back to 1898 and is 2,688 square feet; and the main section dates back to 1908 and is 4,896 square feet. The main floor, or sanctuary/hall, is

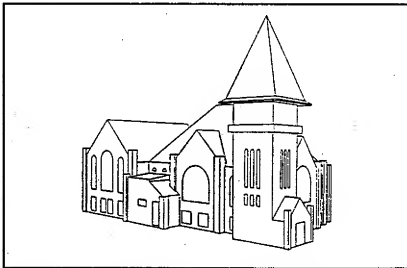


Figure 1 Isometric drawing of St. John UCC, Evanston, Illinois

above a full, conditioned basement with a dropped ceiling. The basement has offices that are occupied from 9 a.m. to 3 p.m., Monday through Saturday. The rest of the basement is used as a classroom from 7 a.m. to 2 p.m. on Sundays, and from 9 a.m. to 5 p.m. on Wednesdays. The sanctuary/hall is used from 7 a.m. to 2 p.m. on Sundays, and from 4 p.m. to 10 p.m. on Thursdays. The thermostat setpoint is 72°F during occupied periods and 68°F during unoccupied periods.

For lighting, the church has a mixture of incandescent and fluorescent lights inside. There is a total of 5 kW of lighting on the main floor, 1.4 kW in the basement, and 0.8 kW of miscellaneous lights. There is one 150 W mercury vapor lamp outside.

The section constructed in 1898 has 2x6 walls that are uninsulated with 1 inch lath and plaster and 1 inch furring on the inside and 2 inch wood sheathing and a 4 inch brick veneer on the outside. The roof is constructed of 240 pound asphalt shingles over 15 pound felt on 3/8 inch plywood decking installed on top of 1x6 nailers with 1 inch gaps. The ceiling is 5/8 inch lath and plaster and the space between the ceiling and roof is not insulated.

The section constructed in 1908, has walls that are 13 inch masonry walls (12 inch brick and 1 inch mortar) with 1 inch lath and plaster and 2 inch furring on the inside. The roof has the same construction as the 1898 roof, except the attic is insulated with 6-inch fiberglass batts. The sanctuary ceiling has four vents and three of them have been covered with boards. To adjust for the vents in the ceiling above the sanctuary, the insulation value is down-graded from a nominal 6 inches to a nominal 4 inches.

Windows

The church has 1153 square feet of windows. Five of the windows are stained glass windows (379 square feet) and have protective glazing. The average cost per square foot of window area for the protective glazing was \$21. The remainder of the windows are a mixture of single-glazed (338 square feet) and double-glazed (436 square feet) windows. For the double-pane windows and the windows with protective glazing, a 3 to 4 inch gap is assumed between the glazing layers.

For this study, three glazing options are considered for the stained glass windows:

- 1) Single glazed: green glass;
- 2) Unvented protective glazing: clear glass (or acrylic) on the outside and green glass on the inside; and
- 3) Vented protective glazing: clear glass (or acrylic) on the outside and green glass on the inside.

Table 1 summarizes the thermal properties of the stained glass window options. The properties were determined using the WINDOW 4.1 computer program (LBL 1994) for calculating the

thermal and optical performance of window systems. The U-factor (or U-value) is a measure of the heat loss through the window and does not account for solar gains. The shading coefficient is a relative measure of the solar heat gain through a window. The solar heat gain coefficient is the fraction of incident solar radiation that comes through a window. (Multiply the shading coefficient by 0.86 to determine the solar heat gain coefficient.) The solar transmittance is the fraction of incident solar radiation that is transmitted through a window. The shading coefficient and solar heat gain coefficient include the transmitted and absorbed components that come through a window.

The glass temperatures are center-of-glass temperatures of the inner glazing layer. We assumed ASHRAE Summer Design Conditions which specify 248 Btu/hr-ft² of directly incident solar radiation, an 89°F outside air temperature and a 75°F room temperature. The "no wind" case is the worst case.

Table 1 - Stained Glass Window Properties

<i>Property</i>	<i>Single</i>	<i>Unvented</i>	<i>Vented</i>
U-Factor (Btu/hr-ft²-F)	1.09	0.50	0.64
Shading Coefficient	0.77	0.70	0.63
Solar Heat Gain Coefficient	0.63	0.60	0.54
Solar Transmittance	0.51	0.36	0.36
Glass Temperature (7.5 mph wind)	106°F	119°F	119°F
Glass Temperature (no wind)	108°F	120°F	120°F

The glass temperatures show that the protective glazing increases the inside glass temperature by 12°F. The calculations in WINDOW 4.1 are based on glazing systems that are unvented, so the results do not show that venting the glazing lowers the glass temperature. The glazing temperature for the Vented option will be between the Single and Unvented options and closer to the Unvented condition.

To simulate the vented glazing option, natural convection is assumed between the glazing layers to determine the U-factor. The solar heat gain coefficient is the average of the contribution of absorbed solar heat gain from the Single and Unvented options added to the solar transmittance. The absorbed solar heat gain is the difference between the solar transmittance and the solar heat gain coefficient.

The remainder of the glazing area is a mixture of single glazed, clear units and double-glazed units. The majority of the windows in the basement are double-glazed, while the majority of the windows in the sanctuary and the main hall are single glazed.

Heating, Ventilation and Air Conditioning

The church has baseboard heat that is served by a gas-fired, hot water heater. The boiler has an input rating of 600,000 Btu/hr and an output rating of 480,000 Btu/hr and is well maintained.

The church has 3 zones, each with its own thermostat: 1) sanctuary/hall; 2) basement (school area); and 3) offices. There is a total of 0.4 hp circulating pumps serving the zones. The office also has a 2500 W window air conditioning unit. The same system is used for the analysis in Seattle and Toronto. For Phoenix and Savannah, three 5-ton electric heat pumps provide heating and cooling.

Electricity and Natural Gas Costs

The average cost for energy in Evanston is \$0.10/kWh and \$0.42/therm. Utility bills for electricity and natural gas usage for May 1994 through April 1995 were provided for the church, and the model was tuned to match the usage. For the other locations, the cost for electricity is \$0.11/kWh and for natural gas is \$0.5/therm.

RESULTS

The DOE-2.1E building simulation program was used to predict the energy savings from the unvented and vented protective glazing as compared to the single-glazed window. The simulation model was tuned to match the monthly utility data to within 5% of the annual energy use. Figures 2 and 3 compare the predicted energy use with the actual energy use for each month. The greatest deviation in the monthly natural gas usage occurs in August and September when the usage was estimated by the utility. On the electricity usage, the model predicts within 5% of the annual usage; however, the monthly values show greater deviation, especially in the summer months. The model overpredicts electricity usage in the summer. This difference can be attributed to weather conditions, and less frequent use of lights and other equipment in the summer.

The actual energy use between May 1994 and April 1995 at St. John UCC was 5941 kWh and 5407 therms. The electricity cost \$605, and the natural gas cost \$2271. Although space heating accounts for over 90% of the energy used at the church, the cost for natural gas is only 79% of the total energy costs.

Figure 4 gives a breakdown of the energy use within the building in Evanston. A similar graph is given for Phoenix in Figure 5. For the other climates, graphs are included in Appendix A. In Evanston, Seattle, and Toronto over 90% of the energy used is for space heating. In Phoenix and Savannah, space cooling accounts for the majority of the energy use.

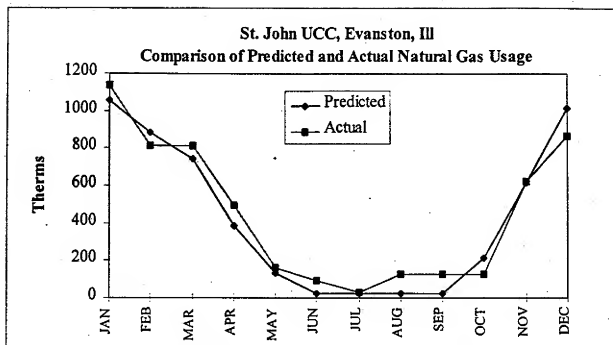


Figure 2 Comparison of actual and predicted natural gas usage in Evanston, Illinois.

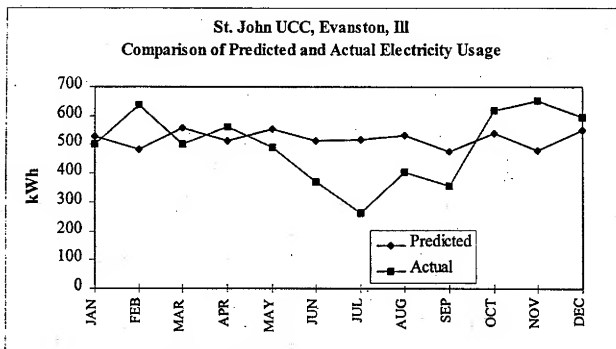


Figure 3 Comparison of actual and predicted electricity usage in Evanston, Illinois.

St. John UCC Energy Use Evanston, Ill

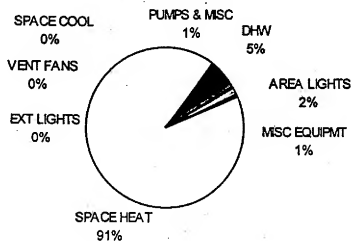


Figure 4 Breakdown of energy use at St. John UCC.

St. John UCC Energy Use Phoenix, AZ

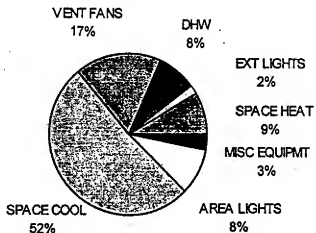


Figure 5 Breakdown of energy use in church in Phoenix, Arizona.

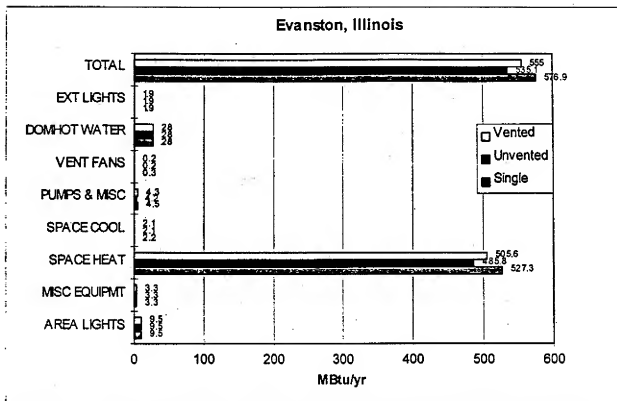


Figure 6 Comparison of end use categories for Single, Unvented, and Vented glazing options in Evanston, IL.

Figure 6 compares the energy use for all end-uses for the single, Unvented, and Vented glazing options in Evanston. The Unvented and Vented glazing options reduce the space heating requirements by 8% and 4% respectively and have a minimal impact on the other loads. The graphs for Seattle and Toronto are similar, and are given in the Appendix. Figure 7 gives the same information for Savannah, except the difference in annual energy use for the options is less than 1%. The results for Phoenix are similar to Savannah and the graph is also included in the Appendix.

Figure 8 shows the annual energy cost for the three glazing options and Figure 9 shows the annual energy cost savings in Evanston predicted by DOE-2.1E. In Evanston, Seattle, and Toronto, the unvented protective glazing affords the greatest energy savings. The colder the climate is that greater the cost savings are. The annual costs savings are \$136 in Seattle, \$183 in Evanston, and \$209 in Toronto. If the installation of protective glazing costs \$12 per square foot, the simple payback ranges between 20 to 30 years. This does not account for costs to replace the protective glazing, which has a 10 to 20 year life.

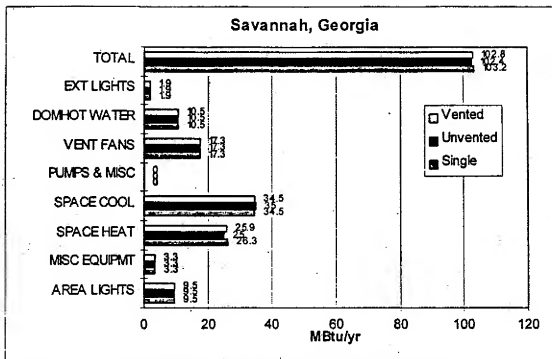


Figure 7 Comparison of end-use categories for Single, Unvented, and Vented glazing options.

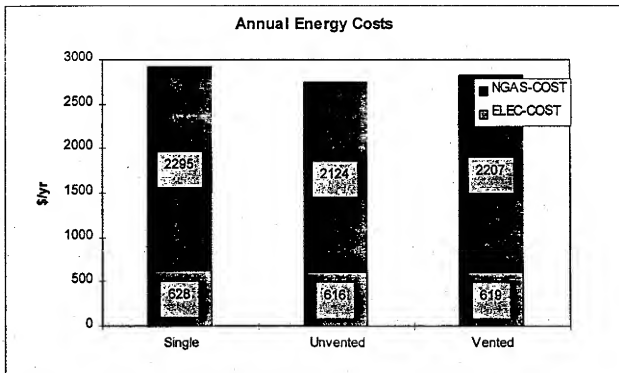


Figure 8 Annual energy costs for St. John UCC in Evanston, IL.

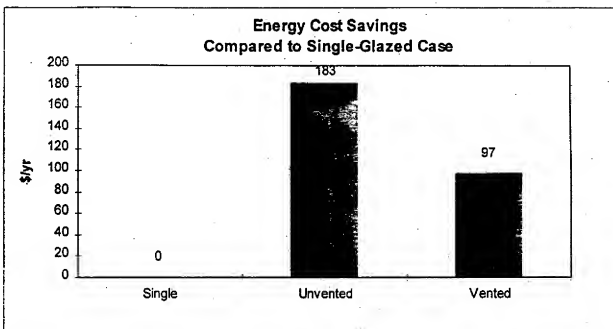


Figure 9 Annual energy cost savings from the Unvented and Vented glazing options for St. John UCC in Evanston, IL.

In Phoenix and Savannah, the annual cost savings are \$8 and \$23 respectively. In Phoenix, the vented option outperforms the other two options because there is almost no heating requirement. In Savannah, the unvented option outperforms the other two options because heating accounts for 25% of the energy use. Graphs showing annual energy costs and savings are shown for all locations in the appendix.

A secondary goal of this study is to identify energy conservation measures which are the most cost effective. This part of the analysis focuses on the Evanston location. Table 2 describes the 6 cases which are considered. Note that Case 1 represents St. John UCC with protective glazing over the stained glass (Unvented glazing option). The energy savings from Cases 2 through 6 would be greater as compared to the Single glazing option.

Table 2 Description of Cases for the Additional Energy Conservation Measures

Case	Description
1	Base Case, Temperature setback = 68°F
2	Base Case, Temperature setback = 62°F
3	Base Case, Temperature setback = 52°F
4	R-11 insulation above old roof, Temperature setback = 68°F
5	R-11 insulation above old roof, Temperature setback = 62°F
6	R-11 insulation above old roof, Temperature setback = 52°F

Of greatest interest is the effect of setting back the thermostat during unoccupied periods.

Because the church is occupied fewer than 40 hours per week, this is a very cost effective action to take. Currently, the thermostat is set back from 72°F to 68°F during unoccupied periods. Cases 2, 3, 5, and 6 consider setting the thermostats back to 62°F and 52°F. In addition, Cases 4 through 6 consider the addition on insulation over the ceiling in the hall (1898 section).

Figure 10 shows the costs saving for Cases 2 through 6 as compared to the base case, Case 1. The energy savings and costs savings are substantially higher with thermostat setback and adding ceiling insulation than with adding protective glazing. Programmable thermostats would pay for themselves in 1 year by setting the temperature back to only 62°F. The ceiling insulation does not have as fast of a payback as the thermostats; however, the simple payback is less than 3 years with or without the programmable thermostats.

The results from Evanston are extrapolated to Seattle and Toronto in Table 3. The estimated savings are based on the percent reduction in space heating energy use in Evanston. The graph showing the energy use by category for Evanston is included in the Appendix. For Seattle and Toronto, an average cost per therm of \$0.5 is used. This same extrapolation could not be made for Phoenix and Savannah because of the difference in heating fuels and heating systems.

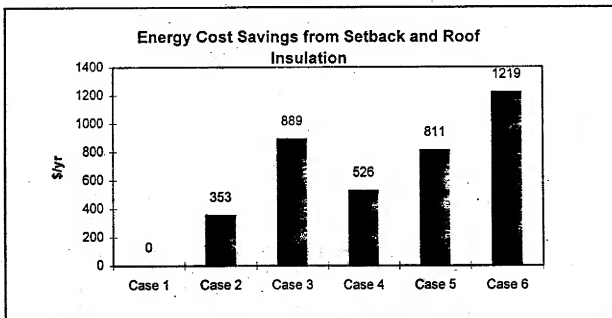


Figure 10 Energy cost savings from temperature setback during unoccupied periods and ceiling insulation in the hall in Evanston.

Table 3 Estimated Energy Cost Savings for Seattle and Toronto

Location	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Evanston	-	353	889	526	811	1219
Seattle	-	338	856	476	747	1143
Toronto	-	528	1339	744	1169	1788

CONCLUSIONS

The results show that the energy savings from protective glazing for an intermittently occupied church do not warrant the expense of the installation. The cost savings are much greater from thermostat setback and from insulating ceilings in cold climates, and these energy conservation measures have simple paybacks of one to three years. In hot climates, sheltering the building from the sun through shades and landscaping are effective means of reducing the energy use and affording greater comfort in the church.

REFERENCES

- Lawrence Berkeley Laboratory. 1993. *DOE-2 Supplement, Version 2.1E*, Lawrence Berkeley Laboratory report no. LBL-8706. Berkeley, CA.
- Lawrence Berkeley Laboratory, Windows and Daylighting Group. 1994. *Window 4.1 Users and Reference Guide*. Berkeley, California.
- S. Reilly, F. Winkelmann, D. Arasteh, and W. Carroll. *Modeling Windows in DOE-2.1E*. Presented at the 1992 DOE/ASHRAE/BTECC Thermal Envelope Conference in Miami, FL (December, 1992).

APPENDIX

**St. John UCC Energy Use
Seattle, WA**

PUMPS & MISC
1%

SPACE COOL
0%

VENT FANS
0%

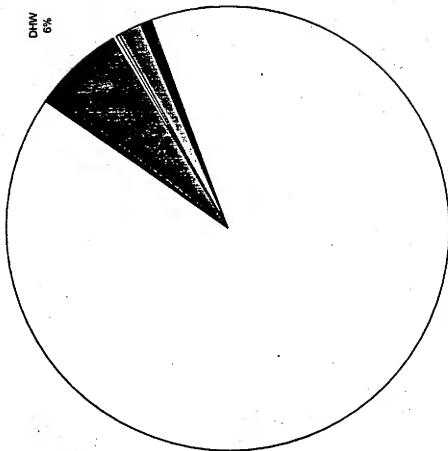
EXT LIGHTS
0%

DHW
6%

AREA LIGHTS
2%

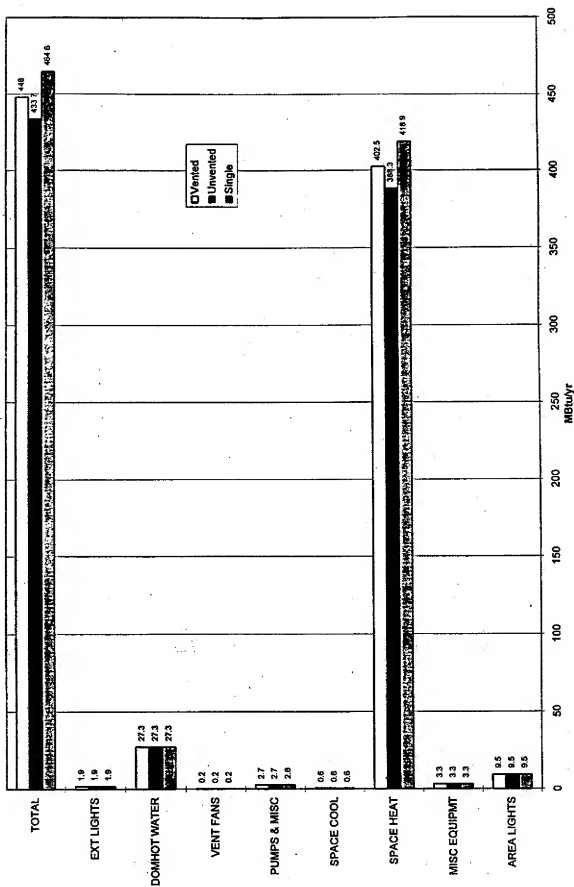
MISC EQUIPMT
1%

SPACE HEAT
90%



Seattle, WA

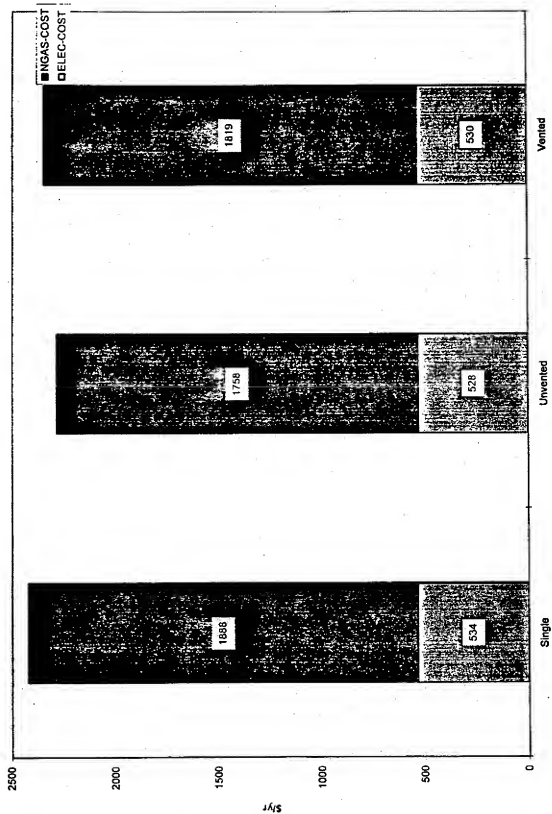
Comparison of Energy Use



St. John UCC

Seattle, WA

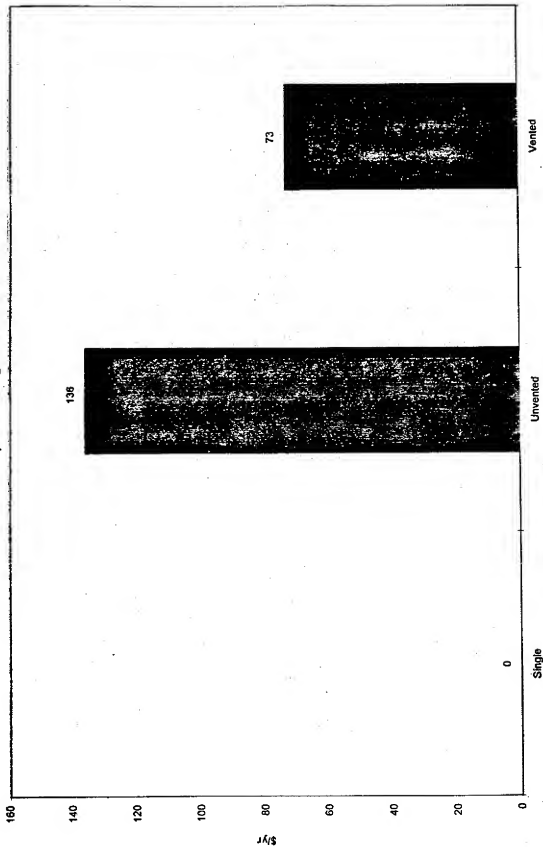
Annual Energy Costs



St. John UCC

Seattle, WA

Energy Cost Savings
Compared to Single-Glazed Case



St. John UCC

**St. John UCC Energy Use
Toronto, ON**

SPACE COOL
0%

VENT FANS
0%

EXT LIGHTS
0%

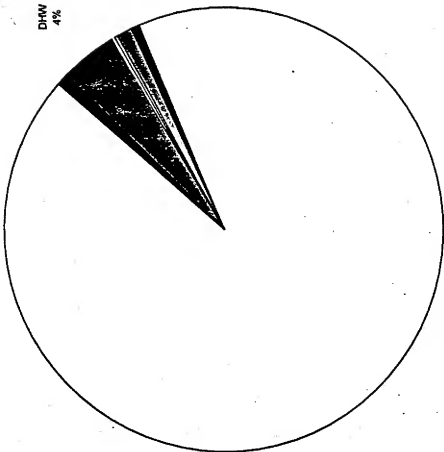
PUMPS & MISC
1%

DHW
4%

AREA LIGHTS
1%

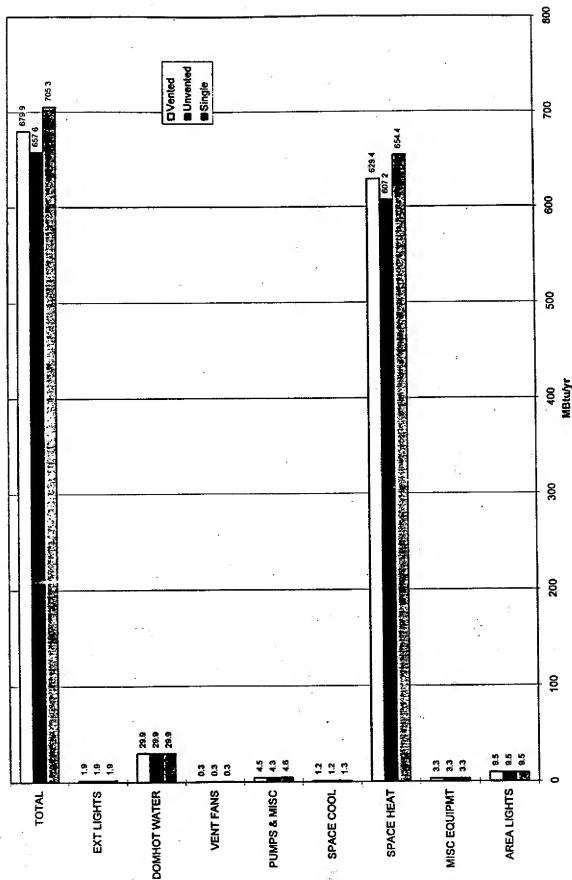
MISC EQUIPMT
0%

SPACE HEAT
93%



Toronto, ON

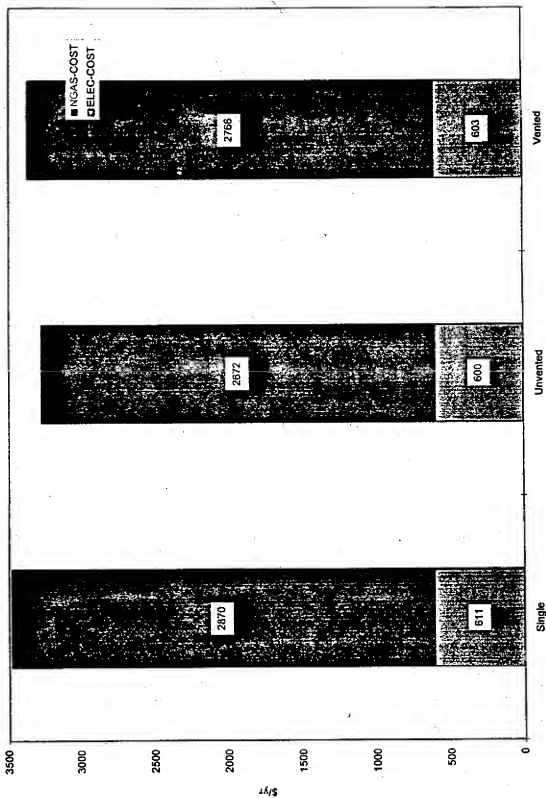
Comparison of Energy Use



St. John UCC

Toronto, ON

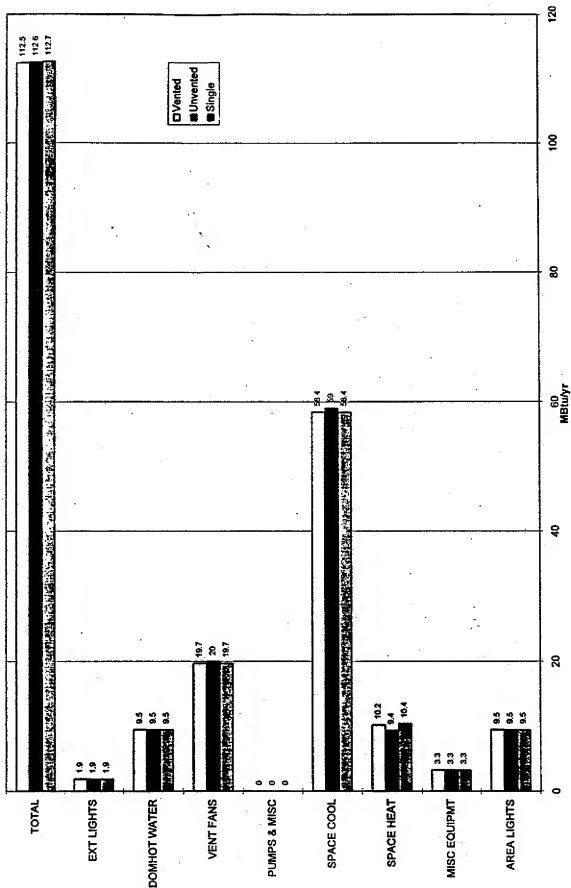
Annual Energy Costs



St. John UCC

Phoenix, AZ

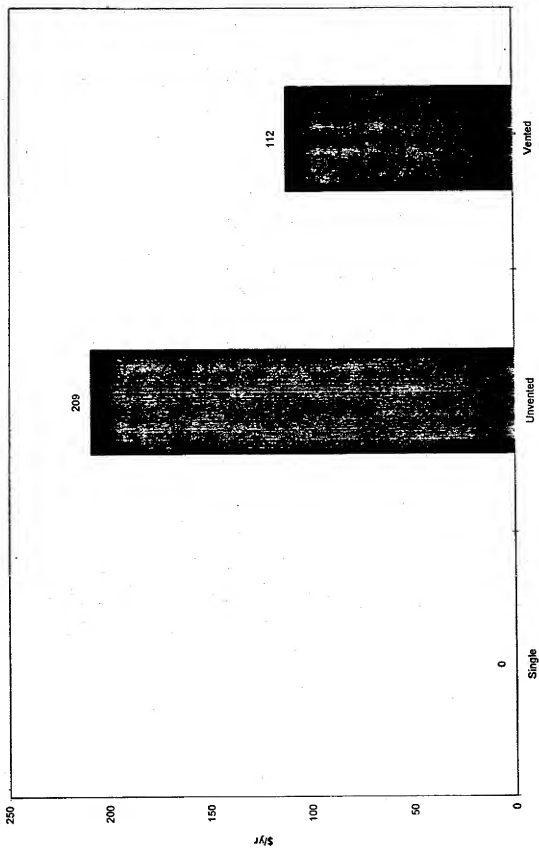
Comparison of Energy Use



St. John UCC

Toronto, ON

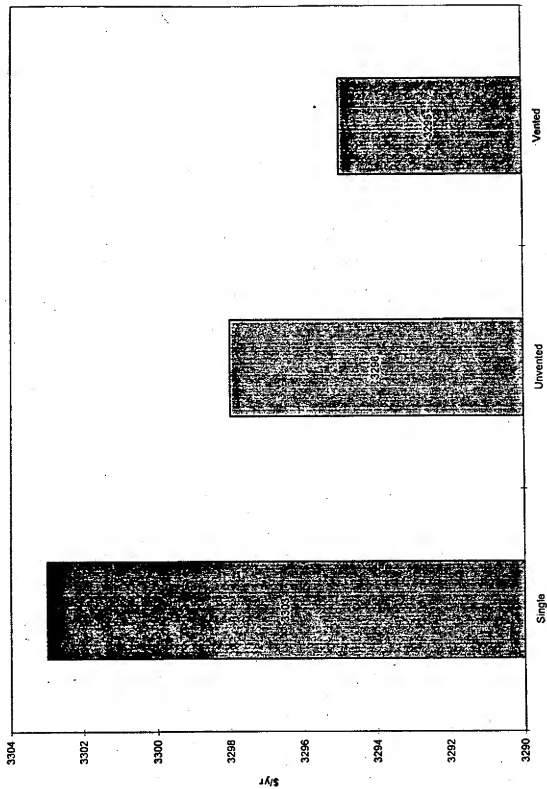
Energy Cost Savings
Compared to Single-Glazed Case



St. John UCC

Phoenix, AZ

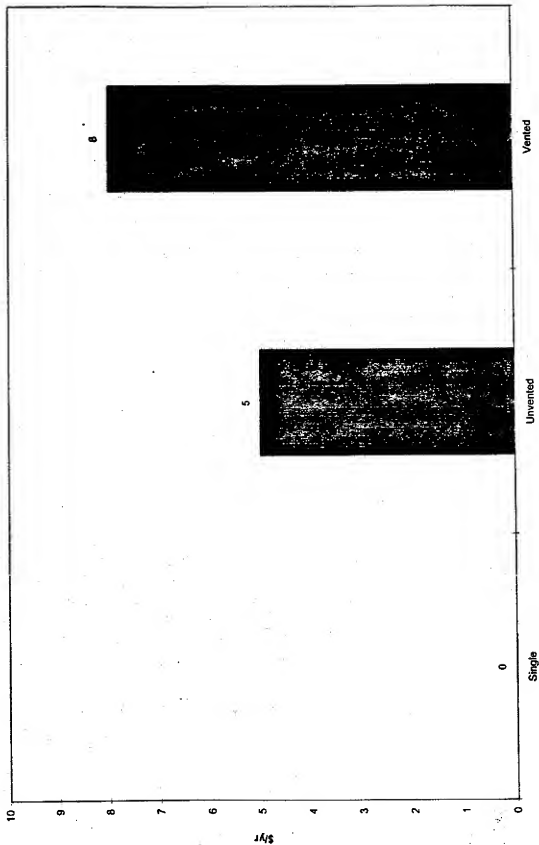
Annual Energy Costs
All Electric



St. John UCC

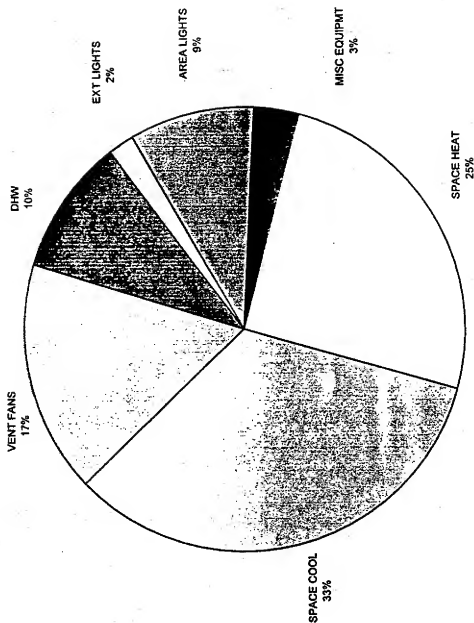
Phoenix, AZ

Energy Cost Savings
Compared to Single-Glazed Case



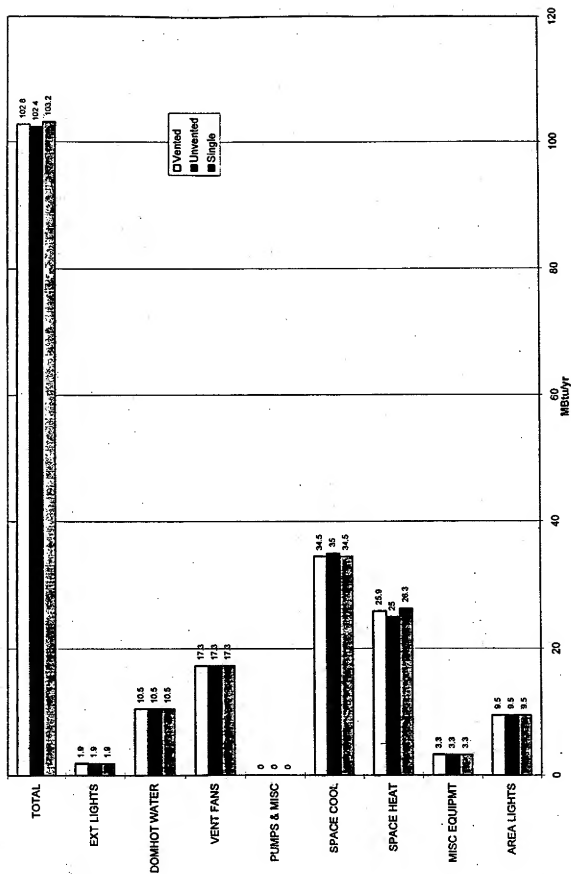
St. John UCC

St. John UCC Energy Use
Savannah, GA



Savannah, GA

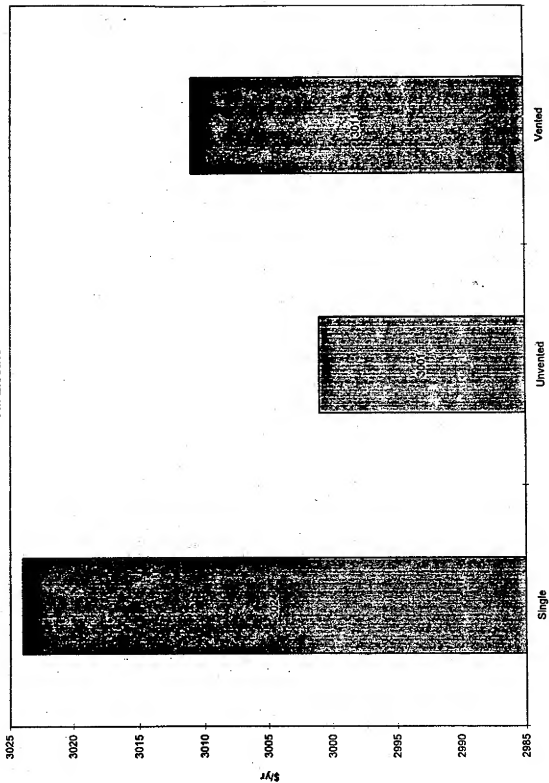
Comparison of Energy Use



St. John UCC

Savannah, GA

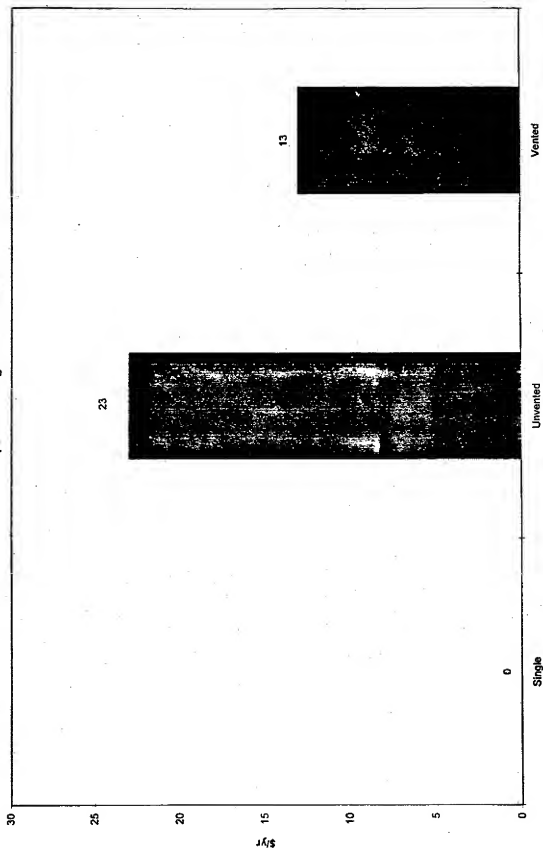
Annual Energy Costs
All Electric



St. John UCC

Savannah, GA

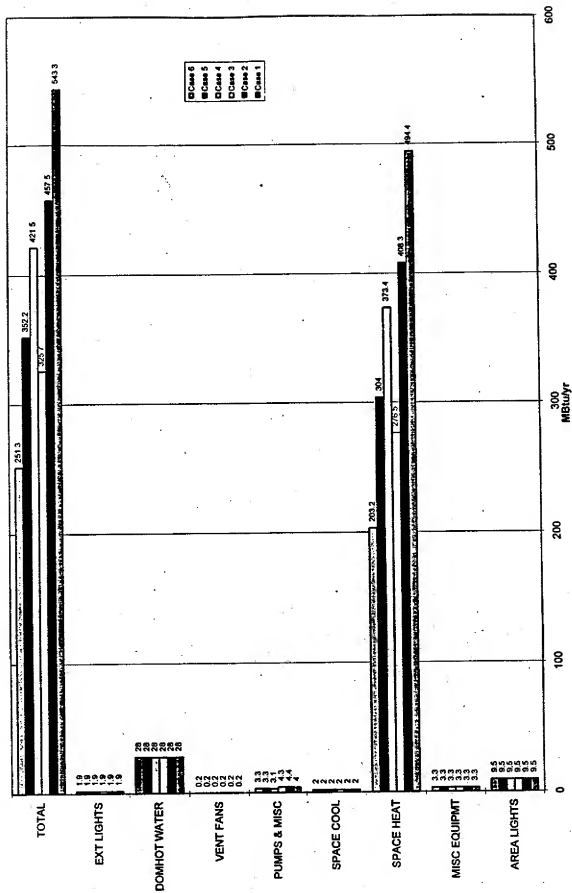
Energy Cost Savings
Compared to Single-Glazed Case



St. John UCC

Evanston, IL

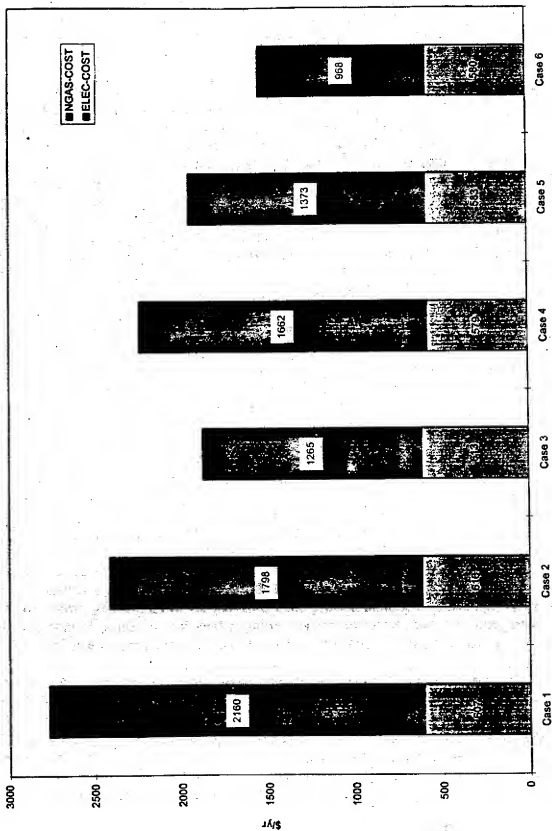
Energy Use



St. John UCC

Evansville, IL

Annual Energy Costs



St. John UCC